



## Development and Performance Evaluation of a Manually Operated Reel Cutter

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### ABSTRACT

Considering the various limitations of electrically powered and internal combusting engine powered reel cutter, such as noise and oil population, and cost of maintenance, manually operated reel cutter which has the potential of eliminating these limitations was developed. The manually operated reel cutter was designed based on design theories on the revolution per minute of the wheel, revolution per minute of the smaller gear, the minimum radius of the blade, the power required to drive the machine, power on the cutter cylinder, axial stress on the handle and minimum diameter of the shaft. The designed mechanical reel cutter was constructed with parts such as the roller, the handle, the side members, shaft, brush bar, blade, and blade reel, afterwards, the parts were assembled to form the mechanical reel cutter. Performance evaluation of the constructed reel cutter showed that the average height of the grasses before mowing was 17.573 cm and the average height of the grasses after mowing was 7.325 cm, denoting a grass height ratio of 2.399. The result of the performance evaluation also gave the cutting efficiency of the developed reel cutter as 88% and the cutting rate of the developed reel cutter as 58.33 m<sup>2</sup>/hr.

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### INTRODUCTION

The tasteful estimation of the environment of a man is as significant as food and sanctuary. Different people have different responses to the environment in which they live or that which surrounds them. For some, they appreciate a very neat and orderly environment, while for others, a much lower degree of neatness and orderliness would be acceptable (Dutta et al., 2016). Generally, grasses can grow in various conditions, hence the need to diminish their growth to improve the magnificence of the living space condition of man. They tend to grow on their own without being planted intentionally and would grow as long as you leave them or till when the environmental conditions are no longer suitable for their survival. Some grasses are stubborn (hard to get rid of) while others could be relatively easy to eliminate. This varying nature and possibilities that come with grasses have made it a major concern especially in residential areas and the external environment generally (Sujendran and Vanitha, 2014).

When grasses are well maintained, they have the potential of beautifying the environment, while on the other hand, they also

have the potential of making it look rowdy and scattered. Taking good care of the grasses in the environment is what makes the difference (Dutta et al., 2016). As man advanced mentally and technologically, grass cutting developed into craftsmanship away from the use of hoes, cutlass and machetes, as was the norm in the early human civilizations. Technology and innovations have brought about efficient and better methods of grass cutting and there is still hope for better methods in the future. It was this technological and innovative era that propelled the invention of a reel cutter (Okafor, 2013).

A reel cutter is a machine utilized for cutting grass or lawn (any area of tough grass which is usually cut like a private garden or open park) (Okafor, 2013). A reel cutter is a tool that by methods of at least one rotating sharp edge cuts grass or different plants to an even length. Reel cutters that utilize edges that turn about a vertical pivot are known as rotational trimmers, while those utilizing an edge gathering that turns about a level pivot are known as chamber or reel trimmers. A wide range of reel cutters exists and have been made to fit a specific purpose (Okokpujie et al., 2017). The choice of the design of reel cutter and user preference



depends on several factors. Such factors could be the cost of purchase of the mower, the cost of maintenance, the ease of use, the efficiency, and sometimes the kind of work to be done with it. Every user has preferences and these preferences are what sponsor their decision on which kind of mower to use (Brenda, 2019).

The cost the traditional method of employing humans to cut grass covering a given area is usually more than the cost of using a reel cutter (Sivagurunathan et al., 2017; Oyedeji et al., 2021). Sometimes the land area to be worked on could be massive, sometimes in multiple hectares and to be able to cut such large areas, several labourers would be required thereby increasing the amount of money required to get the job done. Furthermore, based on environmental limitations associated with grass cutting machines (noise, oil pollution, etc.), the reel cutter has gotten an extraordinary enthusiasm among buyers. Hence, reel cutters have turned out to be extremely basic to our day by day living in keeping up the yards.

From the review of literature, Okafor (2013) designed a simple self-powered reel cutter that uses electricity as its source. The core component of this machine was a battery-controlled dc electric motor. However, due to the presence of many parts such as the belt pulleys, rechargeable battery, alternator, etc, the end weight of the machine was relatively high. Also, Sujendran and Vanitha (2014) designed and fabricated a smart reel cutter for grass trimming in which the device comprises three straight sharp blade edges which were operated with the assistance of the motor, an alternator and the power supply. However, this device is limited by the presence of a power supply and solar radiation. Also, the size of the lawn that can be covered is limited and a grass collector was not provided in this device.

Furthermore, Ibe (2017) designed a hand-held grass cutting machine which was petrol-powered with rotational sharp blade edges for cutting grass in the yard. However, it was also observed that the machine exposed the operator to lots of vibrations and similarly, the operator being closed to the exhaust of the engine, tended to inhale poisonous gases. Okokpuije et al. (2017) also designed, constructed and checked the performance level of a cylindrical reel cutter via an electric engine. Although the noise level of this machine was

relatively lower, the capability of the machine to cover a wider grass area is lower. Also, a grass collector was not incorporated in this design. Also, Adeodu et al. (2018) developed an embedded obstacle avoidance and path planning autonomous solar grass cutting robot tasked for an outdoor environment. However, this machine is similarly dependent on solar radiation and in cases of low radiation or Polar Regions, this machine's performance is low. Shanmugasundar et al. (2018) designed and fabricated an eco-friendly pedal-operated reel cutter for agricultural applications which works on the principle of gears and pedal of a cycle. However, the cutting speed of this mower is dependent on the cycling speed which is in turn dependent on the ability of the user. Also, there is a tendency that the cutting process cannot be used for long, hence its usage is limited to the small-sized area.

As seen from the literature review, although many works have been done on reel cutters, it was observed that there have been limited studies that attempt to harness the conversion of the mechanical energy of the wheel of the reel cutter into rotational energy for the cutting blade edges. This will help reduce the dependency on solar energy, chemical energy or electrical energy. This will also increase the grass area that can be covered and its usage will not be limited by solar radiation. Also, the overall cost of the machine will be reduced due to little maintenance making it more affordable. Hence, this study developed and carried out a performance evaluation of a manual reel cutter.

## MATERIALS AND METHODS

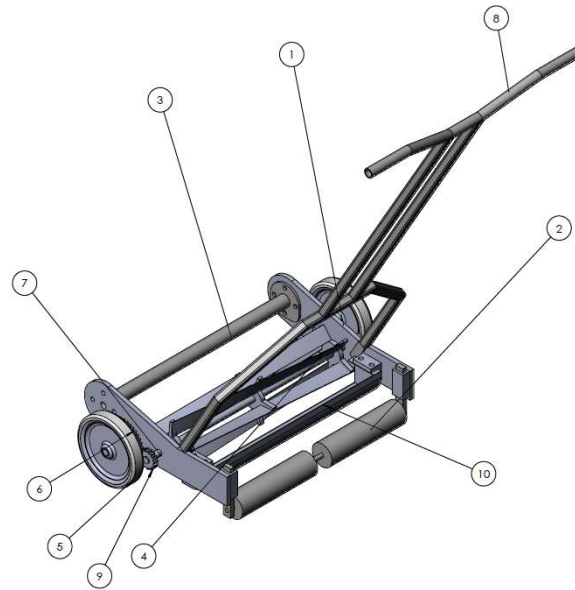
### *Description of the Reel Cutter*

The working principle of the reel cutter is such that an individual pushes on the handlebars which is the source of power application and this propels the wheel of the trimmer forward. As the hub turns, gears start to spin. The configuration of the gear system is that the first gear which is connected to the wheel is of bigger diameter than the small gear which is connected to the rotating blade. Based on the principle of the gear train, the power and torque of the bigger gear are transferred to the smaller gear which results in much higher torque.

The brush bar or rod located at the front of the trimmer helps in bending the tall

grasses and folding them over into the turning sharp blades. Cutting occurs when the turning edges meet the stationary cutter bar located at the back of the trimmer. This meeting point of the blades can be likened to the cutting edges

of a pair of scissors. The chamber gathers up the grass and moves it to the cutter bar and these grasses can be gathered after from the lawn. The schematic of the reel mower is shown in Figure 1.



ITEM NO.	PART NUMBER	QTY.
1	Side Member	2
2	Roller	1
3	Rod	1
4	Blade Assembly	1
5	Wheel	2
6	Big gear	1
7	Wheel Shaft	2
8	Handle	1
9	Small gear	1
10	Grass Collector	1

Figure 1: The Components of the Reel Mower

### Design Considerations

The following design considerations are taken into account for this design:

1. Handgrip was comfortable (padded): Padding the handgrip prevented metal-to-hand contact which may cause some irritations and sometimes injuries.
2. The reel cutter should be lightweight and easy to carry: Material selections for this design were mindful of weight, especially if you have steps to cross over.
3. Large wheels: This enabled easy mowing of the lawn and obstacles can be overcome easily.
4. Compact and easy to store machine.

$$V_w = \frac{\pi D_w N_w}{60}$$

Where,  $D_w$  = Diameter of the wheel (m)

$N_w$  = Rotational speed of the wheel (rpm)

5. The mower has a mulching feature that gives back grass pieces to your lawn which serve as a natural fertilizer.
6. Vibration isolation was obtained by placing a rubber pad at the appropriate spot.

### Design Theories

#### Determination of the Revolution per Minutes of the Wheel

The wheel is the contact point of the mower with the lawn. It is covered with the tire to give grips to the wheel during rotation. The wheel is connected to the attached to the axle which moves the entire system. Speed of wheel is given as (Khurmi & Gupta, 2005):

$$(1)$$

#### Determination of the Revolution per Minutes of the Smaller Gear

The relationship between the diameter of the gear, its module and the number of teeth is given as (Gupta, 2010):

$$D_b = m \times Z_b$$

$$(2)$$



The diameter of small gear,  $D_s = m \times Z_s$  (3)

Where, m= Module of the gear

$Z_b$  = Number of teeth on the bigger gear

$Z_s$  = Number of teeth on the smaller gear

The simple gear speed ratio is given as (Rao & Dukkipati, 2007),

$$\frac{N_b}{N_s} = \frac{D_s}{D_b} \quad (4)$$

Where,  $N_b$  = The rotational speed of the bigger gear. This is the same as the rotational speed of the wheel, that is  $N_b = N_w$

#### Determination of Minimum Radius of the Blade

The design of the blade is such that its maximum shear stress does not exceed the shear stress of the grass. Tresca's criterion theory states that failure occurs when the maximum shear stress  $\tau_b$  exceeds the shear strength with yielding in the uniaxial tension test.

Maximum shear stress of the blade,  $\tau_{blade} = \tau_{max} \times FS$  (5)

The surface area of the blade is given as (Khurmi & Gupta, 2005):

$$A_{blade} = \frac{F_b}{\tau_b} \quad (6)$$

Where  $F_{blade}$  = the tangential force on the blade which is the same as the human effort of pushing and averagely 100N, (Daams & Driken, 1994)

The mean radius of the blade is given as (Lawlor, 1992)

$$R_{blade} = \sqrt{\frac{A_{blade}}{\pi}} \quad (7)$$

#### Determination of the Power required to drive the Machine

The power required to drive the machine is given as (Nkakini & Yabefa, 2014):

$$P_w = P_i + P_r \quad (8)$$

The power required to overcome the inertia of the machine is given as (Lawlor, 1992):

$$P_i = W_m \times V_w \quad (9)$$

The power required to overcome the grass cutting resistance is given as (Nkakini & Yabefa, 2014):

$$P_r = F_r \times R_{blade} \times w_s \quad (10)$$

Where  $W_m$  = The weight of the machine. The approximate weight of the machine can be determined using the SolidWorks 2018 software.

$F_r$  = Cutting Force which is the same as the Tangential force on the blade,  $F_{blade}$

$R_{blade}$  = Minimum Radius of the blade

$w_s$  = Angular speed of the smaller gear, which is the same as the angular speed of the blade.

#### Determination of the Power on the Cutter Cylinder

Power on the cutter cylinder is given as (Nagarajan et al., 2017):

$$P_c = \frac{m_c \times g \times \pi \times D_c \times N_s}{60} \quad (11)$$

Mass of the cutter cylinder is given as (Lawlor, 1992):

$$m_c = l_c \times A_c \times \rho_c \quad (12)$$

The cross-sectional area of the cutter cylinder is given as (Lawlor, 1992):

$$A_c = \frac{\pi d_c^2}{4} \quad (13)$$

Where g = Acceleration due to gravity (9.81m/s<sup>2</sup>)

$D_c$  = Diameter of the cutter cylinder

$A_c$  = Cross-sectional area of the cutter cylinder

$l_c$  = Length of the cutter cylinder



$\rho_c$  = Density of the material of the cutter cylinder (mild steel) which is given as 7850kg/m<sup>3</sup>, (McQueen et al., 1985)

#### Determination of the Axial Stress on the Handle

Axial Stress on the handle is given as (Nagarajan et al., 2017):

$$\sigma_h = \frac{F_h}{A_h} \quad (14)$$

The cross-sectional area of the handle is given as (Lawlor, 1992):

$$A_h = \pi \times d_h \times l_h \quad (15)$$

Where,  $d_h$  = Mean Diameter of the handle

$l_h$  = Length of the handle

$F_h$  = Force Applied on the handle, which is the same as the tangential force on the blade which is the same as the human effort of pushing and is an average of 100N

The ultimate tensile strength of the material,  $\sigma_U = 8.41 \times 10^8 \text{ N/m}^2$  (McQueen et al., 1985)

#### Determination of the Minimum Diameter of the Shaft

Torque on Shaft is given as (Khurmi & Gupta, 2005):

$$T_{shaft} = \frac{P_c \times 60}{2\pi N_s} \quad (16)$$

The minimum diameter of the shaft is given as (Khurmi & Gupta, 2005):

$$d_{shaft} = \sqrt[3]{\frac{16 \times T_{shaft}}{\pi \times \tau_{max}}} \quad (17)$$

Where  $\tau_{max}$  = Maximum allowable shear stress of the shaft in which the maximum allowable shear stress of mild steel is  $2.52 \times 10^8 \text{ N/m}^2$ .

#### Performance Test

The performance evaluation of the reel cutter is based on three field tests namely:

1. **Grass Height Ratio:** This is the parameter that compares the height of the grass before cutting with the height of the grass after cutting. The height of the grass before cutting is determined by measuring the

$$\text{Grass Height Ratio} = \frac{H_a}{H_b} \quad (18)$$

Where

$H_a$  = average height of the grass after mowing,

$H_b$  = average height of the grass before mowing.

The average height of the grasses that made up the test site was measured using a meter rule and afterwards, the developed reel cutter was used to mow the grasses within the grassland. Then the new heights of the grasses after cutting were measured and a comparison of the average height of the grasses before and after mowing was made.

height of random grasses in the area to mow, and obtaining the average with the help of a tape rule, similarly, the height of the grass after cutting is obtained by measuring the height of random grasses in the area mowed. This is given as (Okafor, 2013):

**Cutting Efficiency of the Reel Cutter:** The cutting efficiency of the reel cutter is the parameter that measures the compatibility of the reel cutter with the desired application. It is the measure of the ratio of desired result mowed area with the total mowed area. The desired result mowed area is the area mowed that conforms to the desired height outcome. This is given as (Okafor, 2013):

$$\text{Cutting Efficiency of the Reel Cutter} = \frac{A_d}{A} \times 100 \quad (19)$$

Where

$A_d$  = area with the desired height of cut

$A$  = total Area mowed

**The capacity of the Reel Cutter:** This is the measure of the performance of the reel cutter

which measures the area that can be mowed per hour. This is given as (Ibe, 2017):

$$\text{Capacity of reel cutter (m}^2/\text{hr)} = \frac{A \times 60}{\text{Time taken (mins)}} \quad (20)$$

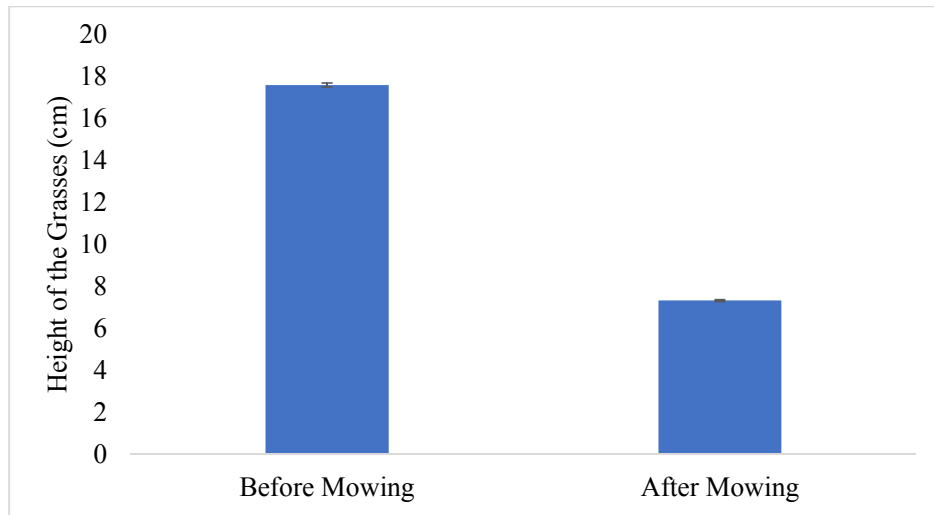
**RESULTS AND DISCUSSION**

The comparison of the average height of the grasses before and after mowing is given in

Figure 3. Figure 2 shows the areas on the test sites mowed and yet to be mowed.



**Figure 2:** Areas on the Test Sites mowed and yet to be mowed



**Figure 3:** Height of the grass before and after mowing.

From the result obtained, the average height of the grasses before mowing was 17.573 cm and the average height of the grasses after mowing was 7.325 cm, hence,

applying Equation (18), the grass height ratio is obtained as 2.399. Also, the result shows that the final grass height obtained from the



developed reel mower falls between 5.08 cm and 8.255 cm (Martini et al., 2015).

**Cutting Efficiency of the Reel Cutter**

To determine the cutting efficiency of the reel cutter, the sum of the areas of the test site with grass height above 8.255 cm as stated by Martini et al. (2015) was obtained. These

areas formed the uncut regions of the test site, and subtracting the uncut regions from the test site gives the area of the test site with acceptable mowed grass height. Applying Equation (19), the cutting efficiency of the developed reel cutter was obtained as tabulated in Table 1.

**Table 1:** Cutting Efficiency of the Reel Cutter

Area of the test site (m <sup>2</sup> )	Area of the test site with acceptable mowed grass height (m <sup>2</sup> )	Cutting efficiency
4	3.52	88%

From the result obtained in Table 1, the cutting efficiency of the developed reel cutter is 88%. This shows an average cutting efficiency, however, where a high level of grass height consistency is necessary, reel cutters with a high cutting efficiency of 95 percent to 99 percent are best employed. Grasslands utilised for sports like football, as well as grasslands used for aesthetic purposes, both require great cutting efficiency. However, for such purposes, this reel cutter would not deliver the necessary results. In comparison with other studies however such as that of Okafor (2013) who

obtained a cutting efficiency of 89.55% for a self-powered electrical reel cutter, the developed reel cutter has a close cutting efficiency.

**Cutting Rate of the Reel Cutter**

In the determination of the capacity of the developed reel cutter, the time taken to mow the test site was measured using a stopwatch. Using Equation (3.20), the capacity of the developed reel cutter was obtained and tabulated in Table 2.

**Table 2:** Cutting rate of the developed reel cutter

Area of the test site (m <sup>2</sup> )	Time taken to mow (minutes)	Cutting rate (m <sup>2</sup> /hr)
4	4.1	58.33

From the result obtained in Table 2, the cutting rate of the developed reel cutter is 58.33 m<sup>2</sup>/hr. Since the working principle of the developed reel cutter is via mechanical motion, the cutting rate is a function of the walking speed of the operator. This implies that for a higher walking operator speed, the efficiency of the reel cutter increases so does the cutting rate since it will take a shorter time for the operator to cover the site. In comparison with the cutting rate of 66.67 m<sup>2</sup>/hr obtained by Okafor (2013) for his self-powered electrical reel cutter, the developed reel cutter has a close cutting rate.

**CONCLUSION**

From the development and performance evaluation of the mechanical reel cutter, the following conclusions were drawn:

- i. The manual reel cutter was successfully designed based on design theories on the revolution per minute of the wheel, revolution per minute of the smaller gear, the minimum radius of the blade, the

power required to drive the machine, power on the cutter cylinder, axial stress on the handle and minimum diameter of the shaft.

- ii. The designed mechanical reel cutter was constructed with parts such as the roller, the handle, the side members, shaft, brush bar, blade, and blade reel, afterwards, the parts were assembled to form the mechanical reel cutter.
- iii. Performance evaluation of the constructed reel cutter was carried out in terms of grass height ratio, cutting efficiency of the reel cutter, and capacity of the reel cutter. The result obtained showed that the grass height ratio is 2.399. The result of the performance evaluation also gave the cutting efficiency of the developed reel cutter as 88% and the cutting rate of the developed reel cutter as 58.33 m<sup>2</sup>/hr.

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